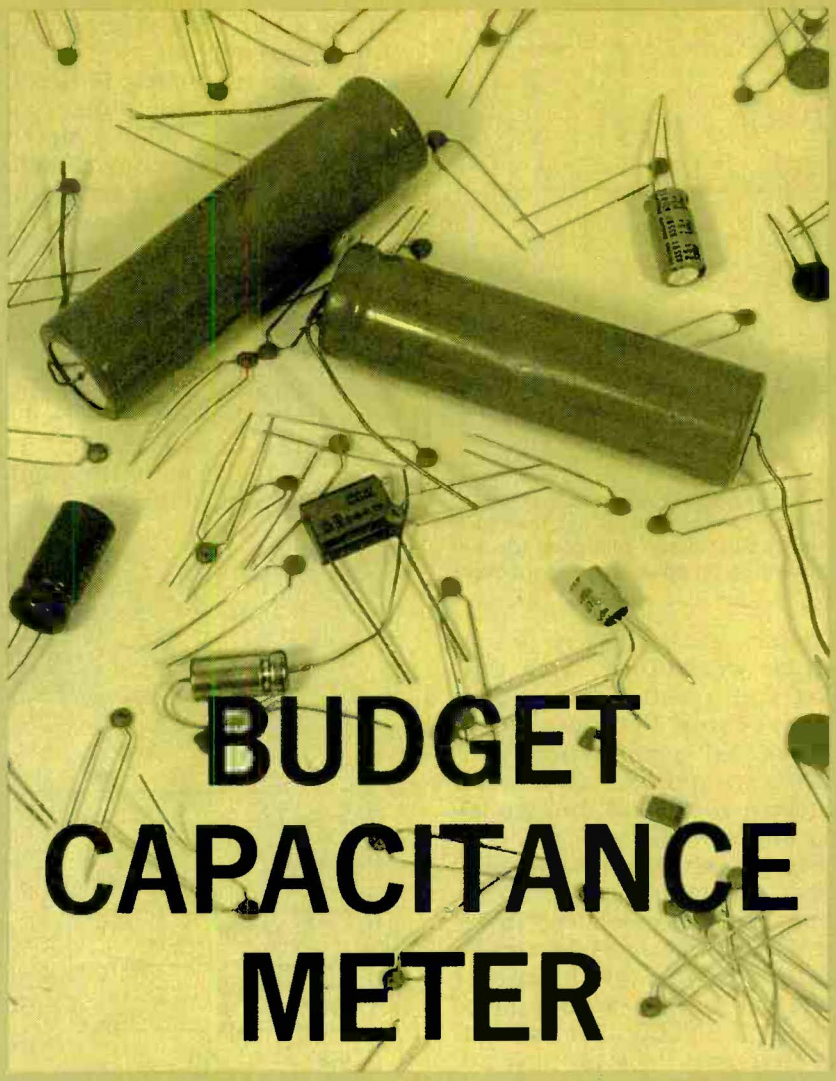
W. E. BABCOCK



BUDGET CAPACITANCE METER

Build a direct-reading capacitance meter.

MOST ELECTRONICS EXPERIMENTERS accumulate, among other things, a large number of capacitors whose values are unknown. The color-coded markings might be worn off, or maybe the true color of the dots or stripes cannot be determined for sure—after a few years knocking around in the junk box the yellows, browns, and reds quite often seem to degrade to some common, indistinguishable color. The electrolyte in electrolytic capacitors often dries out and the capacitance values drop drastically below those printed on the cases. This article describes a simple capacitance meter that you can build to help determine the values of all of your capacitors.

The capacitance meter works by measuring a capacitor's charging current. To understand its operation, take a look at the simplified circuit in Fig. 1-*a*. If the output of the generator is at the +E level, diode D2 will be reverse-biased. In that case, the generator can be replaced by a battery as in the equivalent circuit of Fig. 1-*b*. Capacitor C_X will then charge and will assume the voltage +E, assuming there's no voltage drop in D1 or the meter.

The result is that current flows through the meter while C_X is charging. When the generator output drops to zero the generator can be replaced by a short circuit and the equivalent circuit is shown in Fig. 1-c. If the output of the generator is a single pulse, then the meter will deflect upward momentarily and then drop back to zero. However, if the output of the generator is a continuous train of pulses, the meter will show a steady reading.

The charge on the capacitor (Q) is equal to its capacitance divided by the voltage across it. The formula is $Q = CV$. If the capacitor is charged or discharged over a given time period, both sides of that equation can be divided by the time (t), yielding the formula $Q/t = CV/t$. However, current is the rate of change of charge, or $I = Q/t$, and $1/t$ is the frequency (f). Therefore, the formula can be rewritten as $I = CVf$.

The meter's sensitivity, the desired capacitance measurement range, the supply voltage, and the operating frequency all affect the capacitance meter's design. For example, if a 6-volt supply were used with a 1-milliampere meter movement and a full-scale reading of 10 picofarads were desired, the required operating frequency would be approximately 16.7 megahertz. That would preclude a design based on the popular 555 timer. Even if the supply voltage were to be doubled, the required operating frequency would be over 8 megahertz, still well over the capability of the 555.

If a lower operating frequency is desired, it is not practical to use a 1-milliampere meter movement in the capacitance meter. Even if a more sensitive 200-microampere meter movement were substituted, the circuit would still require an operating frequency outside the capability of a standard, bipolar 555 timer. However, the CMOS TLC555, manufactured by Texas Instruments, has a maximum frequency of 2.1 megahertz, and by choosing scale ranges and the supply voltage

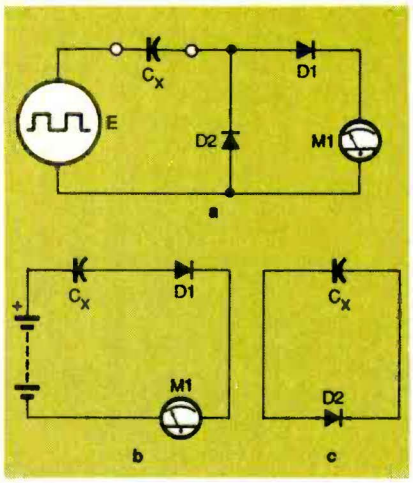


FIG. 1—BASIC CIRCUIT of a direct-reading capacitance meter (*a*), and the equivalent circuits when charging (*b*) and discharging (*c*) an unknown capacitor.

carefully, a satisfactory design can be worked out with that part and a 200-microampere meter. Table 1 shows meter ranges, full-scale meter readings, and approximate operating frequencies assuming a 10-volt supply.

Figure 2 shows the schematic of the capacitance meter incorporating the scales given in Table 1. Each range is a convenient multiple of the meter scale. The author decided not to operate the TLC555 at its highest frequency to avoid any potential problems at the upper limit. To minimize low-frequency meter-needle fluctuations on the two highest capacitance ranges, the author designed the circuit with a full-scale meter current of 2 milliamperes. That made it possible to increase the operating frequency for those ranges by a factor of 10. Even so, the operating frequency for the 20-microfarad range is only 10 hertz.

A single potentiometer (R10) calibrates both the 0.2- and 2-μF ranges. The 250 kilohm potentiometer is adjusted with the range switch S1 in the 0.2-μF position. Then, with S1 in the 2-μF position, the 25-ohm potentiometer shunting the meter (R17) is adjusted to obtain the proper reading. Once that is done, the meter's full-scale deflection will be approximately 2 milliamperes, which is also the proper current range for the 20-μF scale. The operating frequency for the 20-μF scale is approximately 10 hertz, which is fairly close to the resonant frequency of the meter. The meter is damped by a 6600 μF capacitance on the two highest ranges to prevent low-frequency meter-needle fluctuations.

The operating frequency for each range must remain constant if the accuracy of capacitance reading is to be maintained over long time periods. The three timing capacitors (C1–C3) should be of the highest stability available.

Any capacitance coupling between the C_X terminals and between the leads going to these terminals will produce a residual capacitance reading. This residual reading can increase the measured value of very low-value capacitors by a considerable amount. Therefore, a grounded piece of aluminum is located on the rear surface of the panel on which the C_X terminals are mounted to minimize coupling between the terminals, and the two wires going to the terminals are kept separated from each other and from other wires in the circuit.

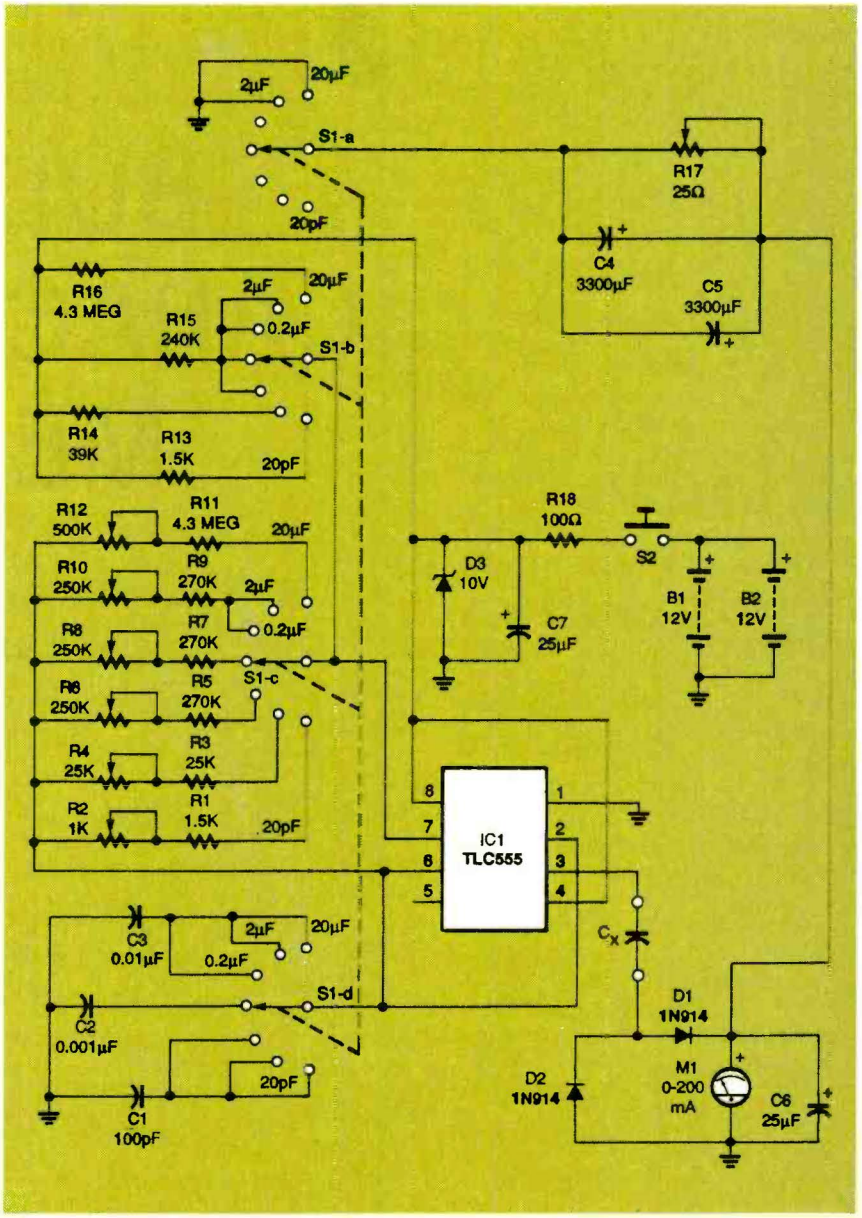


FIG. 2—CAPACITANCE METER SCHEMATIC. The circuit is centered around a TLC555 timer, one that can operate at frequencies up to 2.1 megahertz.

TABLE 1—CURRENT AND OPERATING FREQUENCY

Full-Scale Range	Full-Scale Current	Operating Frequency
20 pF	200 µA	1 MHz
200 pF	200 µA	100 kHz
0.002 µF	200 µA	10 kHz
0.02 µF	200 µA	1 kHz
0.2 µF	200 µA	100 Hz
2 µF	2 mA	100 Hz
20 µF	2 mA	10 Hz

The residual capacitance reading is less than 0.2 picofarads, which should be subtracted from all readings taken on the 20-picofarad scale. The residual capacitance reading can be neglected for ranges that are above 20 picofarads.

Two 12-volt GP23A alkaline cells in parallel power the circuit. Two batteries in parallel are required to supply the 20 milliamperes current required by the circuit. N-cell battery holders work fine as holders for the GP23A batteries. If GP23A batteries are not available, two standard 9-volt batteries connected in series can be used, but the resistor in series with batteries (R18) should be increased to 390 ohms. To prevent unnecessary current drain on the batteries, a pushbutton switch (S2) momentarily applies power to the circuit only while a test is being performed. That extends battery life to near shelf life since the meter will normally be used only for short periods of time.

Construction

The author mounted all circuit components, with the exception of the range switch and off/on switch, on a scrap piece of Formica laminate, a good low-cost substitute for phenolic perforated construction board. Mounting holes for the components were drilled in the board, and components were wired point-to-point on the back side.

Figure 3 shows the completed circuit board, housed in a 3¼- × 6¼- × 2-inch bakelite meter case. Labels for the various ranges were scratched into the bakelite panel with a scribing tool. The scratches were then filled in with white paint. Figure 4 shows the modified meter case.

PARTS LIST

All resistors are ¼-watt, 5%, unless noted.

R1, R13—1500 ohms
R2—1000 ohms, linear taper potentiometer
R3—25,000 ohms
R4—25,000 ohms, linear taper potentiometer
R5—270,000 ohms
R6—250,000 ohms linear taper potentiometer
R7—270,000 ohms
R8—250,000 ohms, linear taper potentiometer
R9—270 ohms
R10—250,000 ohms, linear taper potentiometer
R11, R16—4.3 megohms
R12—500,000 ohms, linear taper potentiometer
R14—39,000 ohms
R15—240 ohms
R17—25 ohms, potentiometer
R18—100 ohms, ½-watt

Capacitors

C1—100 pF, metal film
C2—0.001 µF, metal film
C3—0.01 µF, metal film
C4, C5—3300 µF, 16 volts, electrolytic
C6, C7—25 µF, 16 volts, electrolytic

Semiconductors

IC1—TLC555 timer, Texas Instruments or equivalent
D1, D2—1N914 diode
D3—10-volt Zener diode

Other components

S1—4-pole, 7-position, non-shorting rotary switch
S2—Normally-open SPST pushbutton switch
M1—200 microampere meter movement
B1, B2—GP23 12-volt alkaline battery (or other suitable supply, see text)

Miscellaneous: Two N-cell battery holders, construction board, meter case, wire, solder.

Calibration

Capacitors with known accurate values covering the meter's complete range are necessary to calibrate the capacitance meter. Initial calibration was accomplished by measuring a large number of capacitors covering the complete range and adjusting the appropriate calibrating resistors for each scale to obtain the closest possible agreement with the nominal values across the entire range.

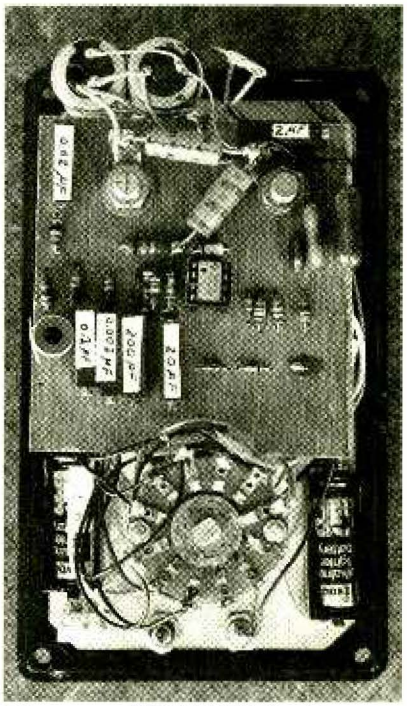


FIG. 3—ALL COMPONENTS, with the exception of the range switch and off/on switch, were mounted on a scrap piece of Formica as a substitute for phenolic perforated construction board. Point-to-point wiring is made on the back side.

Since many capacitors have poor tolerances, some of the meter readings deviate several percent from their nominal values. After completing the calibration as just described, a group of 1-percent tolerance capacitors was first read on the meter without recalibrating, and the maximum deviation from the nominal value was found to be about 11 percent. The meter was then recalibrated

FIG. 4—THE BOARD IS HOUSED in a bakelite meter case. Labels are scratched into the bakelite panel, and the scratches are filled in with white paint.

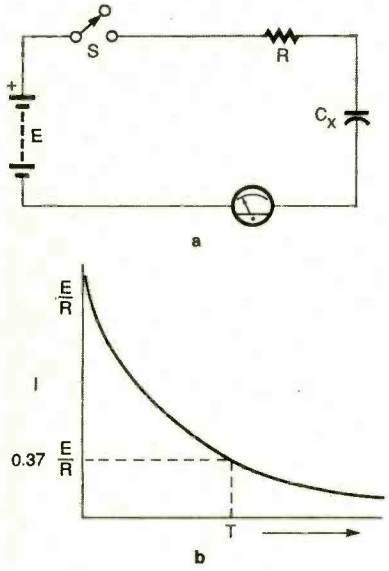


FIG. 5—VALUES FOR LARGE electrolytic capacitors can be obtained by observing the charging characteristic of the capacitor when it is connected to a voltage source through a series resistor (*a*). If the capacitance is unknown, but R and E are known, then C = T/R where T is the time when $I = 0.37 \times I_{INITIAL}$.

using one-percent capacitors with values near midscale for each range.

Practical considerations limit the maximum scale range to 20 microfarads. To add another range covering 200 microfarads would require an operating frequency of 1 hertz or a maximum current range of 4 milliamperes. However, reasonably accurate values for large value electrolytic capacitors can be obtained by observing the charging characteristic of the capacitor when the electrolytic is connected to a voltage source through a series resistor as shown in Fig. 5.

The time constant (T) in seconds of the circuit of Fig. 5-*a* is given by the formula T = RC, where R is the resistance in ohms and C is the capacitance in farads (or megohms and microfarads). As shown in Fig. 5-*b*, at time t = 0 the capacitor will be a short circuit and the current through the resistor will be E/R. The current through the resistor will decay exponentially and, at t = T, will be equal to 37 percent of the initial current. If the capacitance is unknown, but R and E are known, then C = T/R where T is the time when $I = 0.37 \times I_{INITIAL}$.

The procedure for determining an unknown capacitance is as follows:

Choose a value of resistance that will produce a convenient value of initial current. For example, if E = 10 volts, a resistance (R) of 50,000 ohms will produce an initial current reading of 200 microamperes, and 37 percent of that value is 74 microamperes. If the current drops to 74 microamperes in 10 seconds, then C = 10/50,000, which equals 0.0002 farads or 200 microfarads.

The initial current should always be the calculated value. The inertia of the meter movement may prevent the needle from accurately indicating the initial current.

The value chosen for R should always be sufficient to produce an RC time constant (T) of at least 10 seconds. Theoretically, shorter time constants could be used, but in such cases the current would drop so rapidly it would be difficult to obtain an accurate value for the time when it reached 37 percent of its initial value. Ω

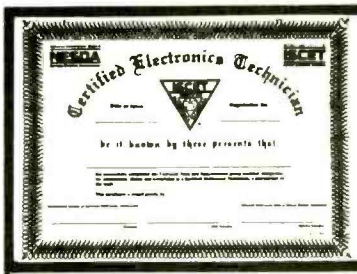
WHAT'S NEWS

continued from page 4

complete module weighs less than its 8.4-inch predecessors.

So far, Toshiba has demonstrated a 9.5-inch VGA TFT prototype that consumes 2 watts and NEC has announced that it plans to introduce a 10-inch LCD that draws 1.5 watts. The present generation of color TFT displays will run down rechargeable nickel-metal hydride (Ni-MH) batteries in the small computers in about two hours. Unfortunately the trend toward larger 10-inch panels will only aggravate the problem because of the general rule that power consumption is proportional to panel area.

ASharp spokesperson said that high production will begin on the improved displays this year and when they reach volume levels, they will be priced lower than the existing 8.4-inch displays. The company also expects to sample a 10.4-inch model later this year. Ω



ADMIT ONE

Your Ticket To

SUCCESS

Over 28,000 technicians have gained admittance worldwide as certified professionals. **Let your ticket start opening doors for you.**

ISCET offers Journeyman certification in Consumer Electronics, Industrial, Medical, Communications, Radar, Computer and Video. For more information, contact the **International Society of Certified Electronics Technicians, 2708 West Berry Street. Fort Worth, TX 76109; (817) 921-9101.**

Name _____

Address _____

City _____

State _____ Zip _____

___ Send material about ISCET and becoming certified.

___ Send one "Study Guide for the Associate Level CET Test." Enclosed is $10 (inc. postage).